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TECHNICAL MEMORANDUM

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 394

TESTING A WINDMILL AIRPLANE ("AUTOGIRO")

By R. Seiferth

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TESTING A WINDMILL AIRPLANE ("AUTOGIRO").*

By R. Seiferth.

In No. IV of this volume (1926) of the "Zeitschrift für Flugtechnik und Motorluftschiffahrt" there appeared an article "Ueber den Autogiro von de la Cierva,"** with the experimental results obtained in the Spanish laboratory at Cuatro Vientos, which were employed for calculating the flight performances of a "windmill airplane," as we shall call it. These calculated flight performances differed so much, however, from those hitherto obtained, as to give rise to doubts concerning the correctness of the tests with models. In the Spanish report it was stated that the reference surface for the calculation of the coefficients c_a and c_w was the area of all four wings. We suspected that this was an error and that the reference surface was really the area of a single wing. When we calculated the flight performances on this assumption, which was subsequently found to be correct, we obtained much more plausible results, as, for example, about 90 km (56 miles) per hour for the maximum speed.

In order to clear up the matter, the model of a windmill airplane (Fig. 1) was tested in the Göttingen wind tunnel. It

* "Untersuchung eines Windradflugzeugs," from "Zeitschrift für Flugtechnik und Motorluftschiffahrt," Nov. 27, 1926, pp. 483-485.

** This article was essentially a German translation of an article published by De La Cierva in "Ingenieria y Construccion" in March, 1924, under the title "Ensayos aerodinamicos de un modelo de autogiro."

was similar to the Spanish model described in No. IV, but had a diameter of only 60 cm (23.62 inches). The four wings of polished basswood were flexibly fastened to the spherical hub by means of plate springs, so that the latter could assume the direction of the resultant of the lift and centrifugal force. Each wing was 24 cm (9.45 in.) long and 4.4 cm (1.73 in.) wide. Once the symmetrical profile 429 (corresponding to the Spanish test) was used, and the other time the cambered profile 387.

In order to be able to hold the windmill in the tunnel, its axis was fastened to a T-shaped support extending in the direction of the air stream. With the aid of a circular guide, divided into degrees, the angle of attack of the windmill plane could be varied between $\alpha = 0$ and 90°. The angle of attack of the profile chord with reference to the windmill plane is designated by β.

The polar and torque curves were plotted for several different angles of attack β. In order to obtain throughout the whole course of a polar curve the most constant possible index value (product of the chord and relative air speed), the rotational speed was kept as constant as possible, by suitably adjusting the wind velocity.

The resistance of the T-support and spherical hub was subtracted from the measured values, so that the resistance values given in the accompanying tables represent only the drag of the revolving wings.

The following consideration was decisive for the calculation of the coefficients c_a, c_w and c_m. Our wing represented a windmill revolving at low speed. In windmills it is customary to determine the resistance for the whole circle and, in general, it is true that c_w at idling speed is always of the order of magnitude of 1, either for a swift runner with only a few narrow wings or a slow runner with many wide wings. It is a natural assumption, however, that the wings are set at the most favorable angle of attack for utilizing the wind energy (smaller for swift runners and larger for slow runners). In this most favorable case c_w is therefore independent of the area of the wings. It may be assumed that a similar principle applies to the lift, so that it seems justifiable, even for windmill wings, to adopt the whole circle as the reference area. Hence we have

$$c_a = \frac{A}{\frac{\rho}{2} v^2 \pi R^2}, \quad c_w = \frac{W}{\frac{\rho}{2} v^2 \pi R^2}, \quad c_m = \frac{M}{\frac{\rho}{2} v^2 \pi R^3} .$$

The reference axis for the longitudinal moment M is the lateral axis passing through the center of the windmill. The reference length is the radius R.

The revolution speed was recorded by the small revolution counter shown in Fig. 1, and stated in the form of the ratio u/v (u being the peripheral speed at the wing tips and v the wind velocity).

At zero angle of attack no measurement could be made, since the revolution speed fell to zero. Thereby the wings were bent by the wind, so that the springs repeatedly broke.

Moreover, in one respect, the mechanical similarity between the model and the full-sized machine could not be attained. On a full-sized "autogiro" the wing moving against the wind is appreciably elevated. During this elevation the angle of attack is diminished and during the succeeding depression it is increased. Since the wing model is relatively much heavier than the full-sized wing, the ratio of the centrifugal force to the lift is much greater and consequently, in the experiment, there was scarcely any noticeable elevation of the wing moving against the wind. It is probably safe to assume, however, that the result is not greatly affected thereby.

The lateral moment, which is naturally of great importance, since the lift is unilateral, was not simultaneously measured. With this the above-mentioned departure from mechanical similarity would probably have been noticeable.

In Fig. 2, a few polar curves are plotted for different angles of attack β. The improvement in the polars for profile 429 is noticeable when β is changed from -4° to 0.5°. There is here an optimum, which is already exceeded at $\beta = -0.5^{\circ}$. The ascending branch of the polar up to $\alpha = 29.9^{\circ}$ is indeed still better than for $\beta = -2^{\circ}$, but, after this angle of attack is exceeded, an abrupt drop in the revolution speed occurs, and consequently the lift and drag both decrease in the same ratio. It is therefore obvious that, even for a windmill airplane, with an unfavorable adjustment of the wings, there may be danger of stalling and pancaking. The best of the plotted polars was obtained by using profile 387 with $\beta = -2^o$.

The Spanish result is plotted with a dashed line. It agrees very well with our polar for profile 429 with $\beta = -2^o$, but shows a greater drag. The coefficients in No. 4 of Z.F.M. (1926) must be divided by 21.7, in order to convert it from the area of one wing to that of the whole circle. The polar curve for a circular disk is also plotted for comparison.

The following tables give the results of the three best experiments.

Windmill Wings of 0.6 m (23.6 in.) Diameter.

I. Wings with Profile No. 387, $\beta = -2^o$.

α	100 c_a	100 c_w	100 c_m	n U/min	u/v
4.9	13.3	3.29	-1.81	1429	2.15
9.8	29.9	8.21	-2.42	1610	3.17
19.7	62.0	28.1	-3.68	1905	4.58
29.6	73.0	50.8	-3.94	1777	5.06
39.7	67.5	64.6	-3.68	1845	5.16
49.7	60.0	81.1	-2.62	1881	5.40
59.7	50.9	96.9	-2.49	1936	5.46
69.9	33.3	106.0	-2.59	1968	5.51
79.9	19.6	110.3	-1.68	1935	5.46
90.0	0	110.3	0	1922	5.42

The wind velocities employed in this experiment can be easily calculated from n and u/v. They vary between 10 and 20 m (32.8-65.6 ft.) per sec. The polar for profile 387, $\beta = -2^\circ$, was taken as the basis of calculation for a windmill airplane. The same data were assumed as in No. 4 of Z.F.M. (1926).

II. Wings with Profile No. 429, $\beta = -0.5^\circ$.

α	100 c_a	100 c_w	100 c_m	n U/min	u/v
9.9	16.3	4.43	-1.70	1820	2.77
19.9	48.8	21.4	-4.3	2360	4.60
24.7	63.5	33.7	-6.2	2230	5.10
29.6	71.8	44.8	-6.8	1910	5.43
29.8	64.2	40.8	-5.37	2200	4.39
29.8	41.0	27.5	-4.40	1765	2.67
29.9	14.8	9.56	-1.1	740	2.09
39.9	16.2	16.2	-1.51	623	0.95
59.9	19.2	34.6	-2.1	970	1.47
90.0	0	50.7	0	844	1.67

III. Wings with Profile No. 429, $\beta = -2^\circ$.

α	100 c_a	100 c_w	100 c_m	n U/min	u/v
2.5	2.97	0.52	-0.39	927	0.72
5.0	4.62	1.1	-0.73	1560	1.55
9.9	16.4	4.5	-1.43	2143	3.16
14.9	29.3	10.5	-2.00	2152	4.28
19.8	41.4	18.9	-2.81	2125	5.11
24.7	50.5	28.3	-3.99	2060	5.79
29.7	58.7	38.6	-5.47	2125	6.23
39.7	58.1	53.4	-6.20	2120	6.60
49.7	51.3	66.6	-4.43	2088	6.81
59.8	43.8	75.5	-4.16	2145	7.03
69.9	29.8	92.5	-1.98	2060	7.27
79.9	17.2	100.8	-1.94	2108	7.52
90.0	0	105.6	0	2108	7.45

Total weight $G = 800$ kg (1763.7 lb.),
Engine power $N_0 = 120$ HP,
Diameter of windmill $D = 11$ m (36 ft.).

The propeller efficiency was estimated at $\eta = 65\%$. The coefficient of the induced drag for fuselage, landing gear, etc., must, since our reference surface is very large, be correspondingly small and can be put at $100\ c_w = 0.66$. Therewith was calculated the speed for horizontal flight.

$$v = \sqrt{\frac{G}{\frac{\rho}{2}\ c_a\ F}}\ \text{m/s};$$

the corresponding engine power

$$N = c_{w\,ges} \frac{\rho}{2} \frac{v^3 F}{75 \eta} \text{ HP. ;}$$

the possible climbing speed

$$\sigma_{st} = \frac{75 (N_o - N) \eta}{G} \text{ m/s ;}$$

with the available engine power of 120 HP., and plotted against c_a in Fig. 3. The speed of the horizontal flight just before landing, which depends on $c_{a\,max}$, is 13.5 m (44.3 ft.) per sec., while the speed range attainable with 120 HP. is 14–26 m (46-85 ft.) per sec., or a maximum of 94 kilometers (58.4 miles) per hour. The maximum climbing speed is 1.05 m (3.44 ft.) per sec.

The same as for any other airplane, the landing speed can probably be further diminished by a suitable rising just before landing. Immediately after landing, the speed will be rapidly diminished by the great resistance.

Since it is an especial advantage of a windmill airplane that it can land almost vertically, we will briefly discuss the conditions in gliding flight. In Fig. 4 we have plotted, against the angle of attack, the speed on the inclined path of glide

$$v_{gl} = \sqrt{\frac{G}{\frac{\rho}{2} c_r F}} \text{ m/s ;}$$

its vertical component, the sinking speed,

$$\sigma_s = v_{gl} \frac{c_{w\,ges}}{c_r} \text{ m/s ;}$$

(in which c_r is the resultant of c_a and $c_{w\,ges}$) and the ratio c_a/c_w ges, which determines the slope of the glide. For the minimum sinking speed σ_s = 5.7 m (18.7 ft.) per sec., c_a/c_w ges = 2.8 corresponding to a slope of 19-20°. A steeper descent is probably possible, in so far as the control is not too greatly impaired thereby, but due to the great sinking speed of about 10 m (33 ft.) per sec., only when a timely transition is made to nearly horizontal gliding flight. De la Cierva himself writes that, in his sixth airplane, he brought the center of gravity in advance of the center of lift, so that in case of stalling, the airplane would automatically tip forward.

Even with a windmill airplane, there is a possibility of diving, as is obvious from the description of the experiment. If the angle of attack is suddenly reduced to zero, the revolution speed and consequently the lift are immediately much diminished. The result is a dive, which may possibly be terminated by righting the airplane.

The object of this article is to recall the optimism, which has repeatedly manifested itself lately, to a more reasonable status. This new kind of aircraft, in spite of its high power requirement, will doubtless serve many special purposes, on account of its low landing speed, easy controllability and insensitivity to gusts. It is also possible that, through some change in the shape of the wings, a little further improvement can yet be attained in its flight performances, but the essential points have probably been covered by the above researches.

Translation by Dwight M. Miner,
National Advisory Committee for Aeronautics.

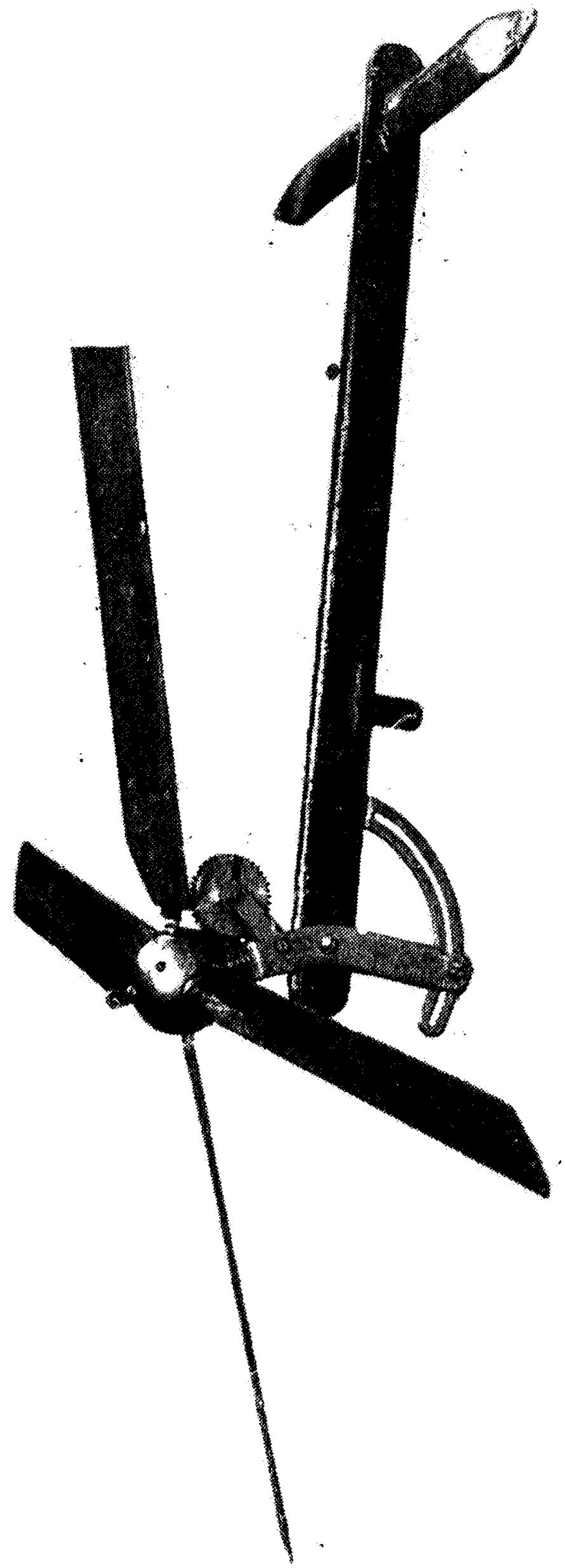

Fig.1

3767 A.S.

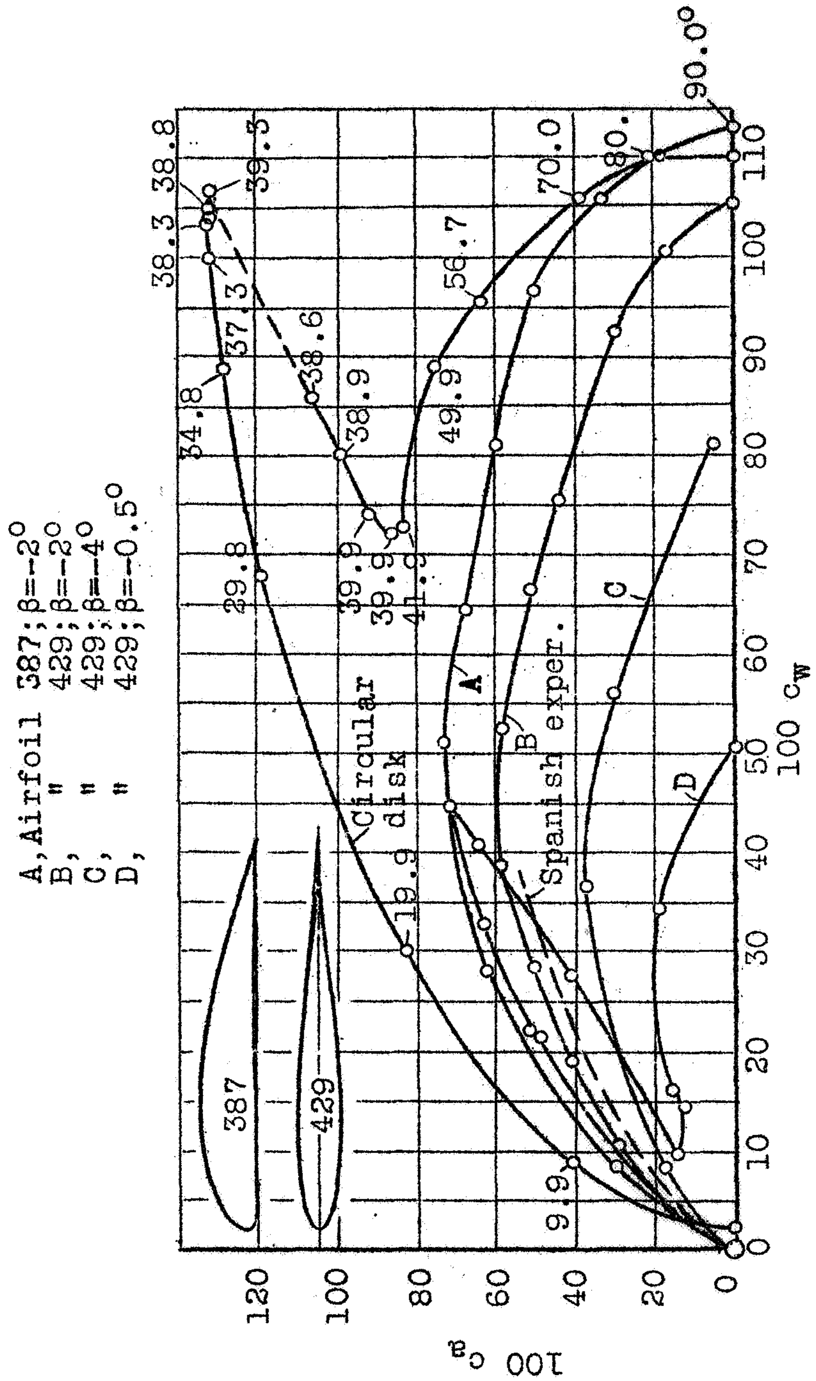
A, Airfoil 387; β=-2°
B, " 429; β=-2°
C, " 429; β=-4°
D, " 429; β=-0.5°
387
429
Circular disk
Spanish exper.
100 c_a
100 c_w
A
B
C
D
90.0°
80.
70.0
56.7
49.9
38.3
38.8
39.5
37.3
38.6
38.9
34.8
29.8
39.9
41.9
19.9
9.9

Fig.2

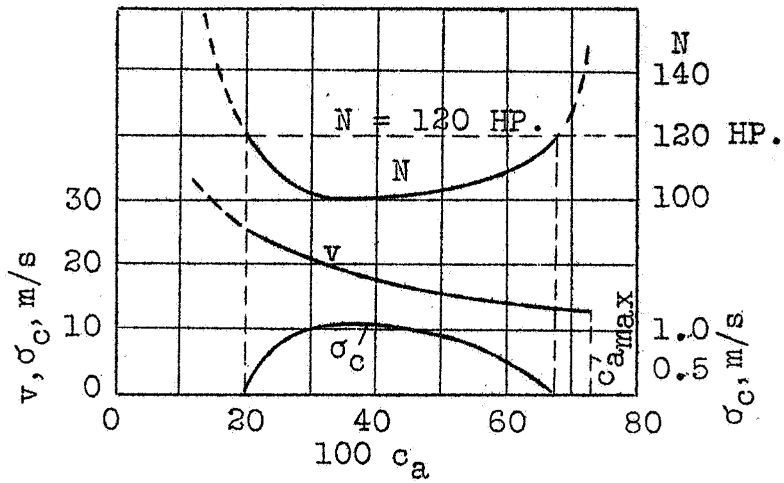
N
140
N = 120 HP.
120 HP.
N
100
30
v
20
v, σc, m/s
10
1.0
σc
camax
0.5
σc, m/s
0
0
20
40
60
80
100 ca

Fig.3

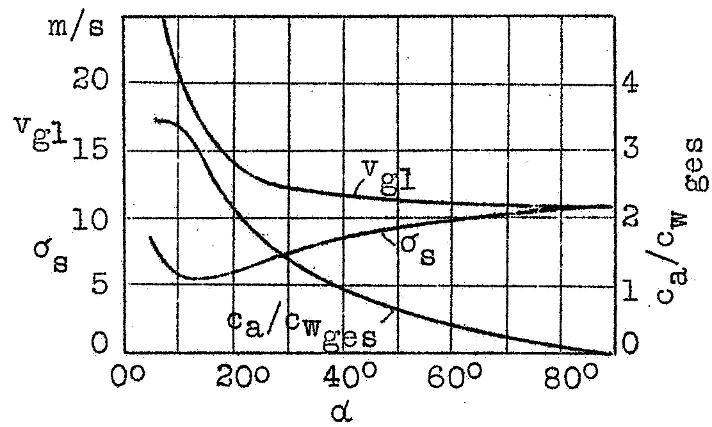
m/s
20
4
vgl
15
3
vgl
10
2
ca/cw ges
σs
σs
5
1
ca/cwges
0
0
0°
20°
40°
60°
80°
α

Fig.4